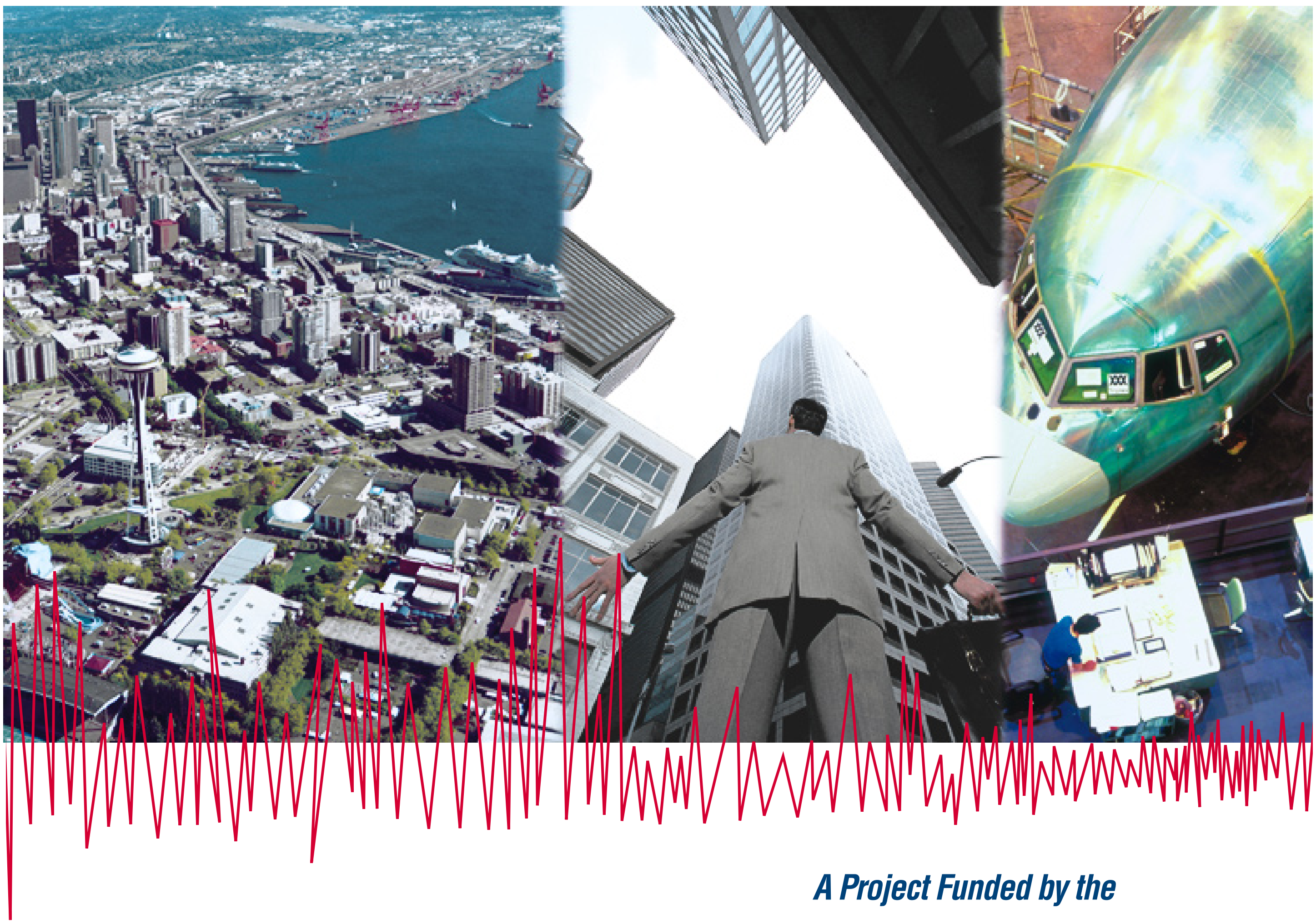
Scenario for a Magnitude 6.7 Earthquake on the Seattle Fault

Excerpts from a publication of the same title to be released March 2005



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and the

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The Project Team

The Seattle Fault Earthquake Scenario project was the result of the vision and effort of professionals from various disciplines and organizations in the Puget Sound region who work daily to improve the earthquake safety of the region's communities and people.

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Hundreds of hours of in-kind support from geologists, seismologists, engineers, planners, and emergency managers from many public agencies and private organizations in the Puget Sound region were required to complete this project.

■ *Organizations providing significant and key contributions to the project are the:*

American Society of Civil Engineers, Seattle, WA

U.S. Geological Survey, Golden, CO, Menlo Park, CA, and Seattle, WA

Structural Engineers Association of Washington, Seattle, WA

Washington Military Department's Emergency Management Division, Camp Murray, WA

Earthquake Engineering Research Institute, Oakland, CA

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A complete list of contributors and reviewers of the Seattle Fault Earthquake Scenario project is in Appendix B, Acknowledgements.

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Without the support of these organizations, this scenario project and publication would not exist.

Introduction

Earthquakes pose a serious threat to life and property in Washington, particularly the Puget Sound region. A 2001 study by the Federal Emergency Management Agency found the state has the second highest risk of economic loss caused by earthquakes in the nation, behind only California. Seattle ranks seventh among cities nationwide at economic risk to earthquakes; Tacoma ranks 22nd.

The most recent significant event to strike the state was the February, 28, 2001 moment-magnitude 6.8 Nisqually earthquake. It caused $2 to 4 billion in damage, primarily from Olympia north through Seattle.

Many believe that the Nisqually earthquake was the largest that could hit the Puget Sound region, and that they are prepared for the next large seismic event.

However, the Nisqually earthquake was not the region's "big one," an earthquake that would cause devastating damage and widespread disruption to transportation systems, utilities, the economy, and (at least temporarily) to the region's way of life, as earthquakes in the past 15 years have in the San Francisco Bay Area, Los Angeles, and Kobe, Japan.

Research in recent years has uncovered active surface fault zones capable of generating major earthquakes in the Puget Sound region. One, the Seattle Fault Zone,[1] runs through the Central Puget Sound region, from Hood Canal in the west, through Puget Sound and south Seattle, and east through Bellevue and Issaquah, roughly parallel to Interstate 90.

This project examines the consequences of a scenario M6.7 earthquake on the northernmost strand of the fault zone, which has the potential for generating the most damaging earthquake seen to date in the United States. It also provides recommendations to local and state policy makers for improving the region's – and the state's – earthquake safety.

An 11-member multi-agency, multi-disciplinary team spent the past three years developing this project. The project team's goal was to prepare a credible description of earthquake damages and impacts that would help elected officials, building owners, engineers, architects, emergency managers, land-use planners, and others prepare a response to such an event, as well as serve as a basis for reducing earthquake risks to life and property.

Describing Damages, Impacts of the Scenario Earthquake

The damages and impacts described throughout this document represent the consensus of project contributors and reviewers of what will happen following the scenario M6.7 earthquake. In all, about 100 individuals with expertise in civil and structural

[1] The terms Seattle Fault Zone and Seattle Fault are used interchangeably throughout this document. The fault zone has a number of strands. The scenario earthquake occurs on the northernmost strand of the fault zone.

engineering, local and state emergency management, land-use planning, seismology and geology, geographic information systems, and other professions, participated in the development of this project. All were volunteers who received no funding for their efforts.

An actual fault rupture on the Seattle Fault found in Bellevue in the late 1990s provides the model for the scenario earthquake. The time of day the scenario M6.7 earthquake occurs – 11:37 a.m. – is the worst for human casualties, because most people are involved in activities outside their home – working, at school, shopping, for example – and are more likely to be in buildings that do not perform as well as their wood-frame residential structures. The descriptions in the text of the effects of the scenario event may differ somewhat from those generated by an actual earthquake of similar magnitude on the Seattle Fault. The timelines provided in the narrative for facility closures and reduced-service periods are estimates that depend in part on the commitment, organization, funding, and sheer will of the responding organizations.

In developing this project, project participants used existing studies, information developed by regional and national experts in engineering, earthquake science, and emergency management, and modest additional studies, including a loss-estimation projection produced by HAZUS, short for Hazards US, a computer-based loss-estimation model developed by FEMA and the National Institute of Building Sciences. (For more on HAZUS, see page 7.)

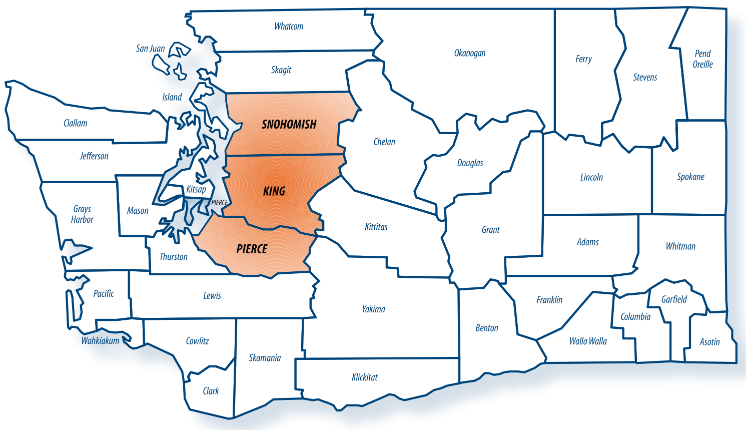
Why Study the Seattle Fault Zone?

The U.S. Geological Survey last developed an earthquake risk assessment for the Central Puget Sound region in 1975. Since that time, understanding of the earthquake risk and the region's population and economy have grown significantly. This has resulted in a much larger exposure to earthquakes than previously imagined.

Until the late 1980s, experts thought the greatest threat posed to the region was from earthquakes deep in the earth's crust, similar to events in 1946 (M6.4), 1949 (M6.8), 1965 (M6.5), and 2001 (M6.8). These earthquakes occur about every 35 to 50 years.

Scientists discovered the Seattle Fault in 1965 when studying gravity data for the Puget Sound region. In 1987, scientists began finding evidence of great earthquakes of M8 to M9 in the Cascadia Subduction Zone off the Washington Coast; these earthquakes occur about every 500 to 600 years. Five years later, a team of scientists discovered the first evidence that the Seattle Fault was active – a M7.3 earthquake that also generated a tsunami in Puget Sound about 1,100 years ago. In the mid to late 1990s, scientists using high-resolution imaging found evidence of other surface faults. Field evidence show large earthquakes with magnitude 6.5 or greater have occurred on six major fault systems in the Puget Sound region. Scientists estimate these earthquakes occur about once every 333 years.

The project team chose the Seattle Fault Zone for examination because it cuts through the state's most heavily urbanized and industrialized area. The team wanted to explore how a M6.7 earthquake on the fault – a smaller event than occurred 1,100 years ago – would affect the people and economy of the Central Puget Sound region. Specifically, the team wanted to know what this earthquake would do to the region's buildings and major structures, its lifeline and transportation systems, its people and communities, its emergency response and recovery, and its economy.



Seattle Fault Scenario Study Region

The Study Area

The scenario steering committee chose a three-county area in which to study the impacts of a M6.7 earthquake on the Seattle Fault – Snohomish County to the north, King County, through which the fault zone runs, and Pierce County to the south (see map above).

Together, these counties have more than half (3.1 million) of the state's 6.1 million population.

The region is home to six of the state's 10 largest cities – Seattle, Tacoma, Bellevue, Everett, Federal Way, and Kent.

Fortune 500 companies headquartered in the region are Costco, Microsoft, Weyerhaeuser, Washington Mutual, Paccar, Safeco, Nordstrom, Amazon.com, and Starbucks.

Major private employers include The Boeing Co., Safeway Inc., Group Health Cooperative, Providence Health System, Swedish Medical Center, Bank of America, and Alaska Air Group. Major public employers include the US Army (Fort Lewis and Madigan Army Medical Center), US Air Force (McChord AFB), US Navy (Naval Station Everett), and the University of Washington.

The Ports of Seattle and Tacoma annually move more than half of all goods shipped internationally from the state ($57 billion of $107 billion in 2001).

Top exports include aircraft and aircraft parts, and agricultural and wood products; The Boeing Co., manufacturer of commercial aircraft, is the nation's largest exporter.

Seattle-Tacoma International Airport is the 15th busiest airport in the nation, moving 26.6 million passengers and 400,500 metric tons of cargo in 2002.

The median household income in each of the three counties is above the state average of $44,776 (King County, ranks #1, $55,157; Snohomish County, #2, $53,060; Pierce County #8, $45,204).

Limitations of the Scenario

The Seattle Fault Earthquake Scenario has limitations, as major studies typically do. The three major issues that this scenario document does not explicitly address are aftershocks, the generation of a tsunami or seiches, and fires.

Aftershocks

Aftershocks will occur following a crustal earthquake such as the scenario event. Aftershocks for the scenario earthquake could reach magnitude 6.0 or greater. They disrupt impacted communities by causing additional damage to already weakened buildings and infrastructure, impeding relief efforts by making it unsafe to enter damaged buildings, causing more injuries and deaths, and placing an enormous toll on the mental health of an already shattered community.

The project team decided early in its work not to specifically address aftershocks, believing that this would complicate an already complex analysis of the scenario event without adding substantially to the information presented.

As a crustal earthquake, the M6.7 scenario event would generate significant aftershock activity, probably similar in nature to those produced by recent California, Japan, and Taiwan crustal earthquakes.

Hundreds of aftershocks occurred after the M6.9 1989 Loma Prieta event, the M6.7 1994 Northridge earthquake, the M6.9 1995 Kobe event, and the M7.6 1999 Chi-Chi earthquake in Taiwan. Both the Loma Prieta and Northridge earthquakes had a significant number of aftershocks greater than magnitude 4.0 within the first week to 10 days after the main shock (Loma Prieta – 20, Northridge – 13). The much larger Chi-Chi earthquake had a number of aftershocks ranging from M6.0 to M6.8 in the five days after the main shock.

Tsunamis and seiches

Large earthquakes can generate tsunamis, damaging waves that result from movement in the water column caused by deformation of the sea floor or lakebed. Earthquakes also cause seiches, waves in an enclosed or partially enclosed body of water that are similar to sloshing in a bathtub.

Generation of a tsunami in Puget Sound appears unlikely given that the fault rupture of the scenario M6.7 earthquake does not result in changes to the sea floor of the sound. Correspondence with staff at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Lab, however, indicates the scenario event most likely would lead to some inundation and potentially dangerous and damaging water currents along the Seattle waterfront.

Tsunamis are possible in Lake Washington and Lake Sammamish, since the fault rupture crosses the lakes, changes shoreline elevations, and may change elevations in the lakebeds.

The scenario earthquake most certainly would generate damaging seiches in bodies of water throughout the study region. Like tsunamis, seiches threaten people and structures such as marinas, bridges and structures on or near shorelines. Of particular note is Lake Union, which has a history of seiches from both local and distant earthquakes that damaged houseboats in the lake, buckled their moorings, and broke their sewer and water lines.

Despite the possibility of tsunamis and seiches, the project team did not examine their impacts. Needed is additional research and modeling to determine whether the scenario earthquake indeed would generate a tsunami and to determine the extent of seiches throughout the study area.

About 1,100 years ago, a M7.3 earthquake on the Seattle Fault – much larger than the scenario event – created uplift on the floor of Puget Sound and generated a tsunami. The tsunami deposited sand sheets on West Point in Seattle, at Cultus Bay on southern Whidbey Island, and along tributaries of the Snohomish River between Everett and Marysville. Computer simulations by the Pacific Marine Environmental Laboratory show the tsunami reached heights of 10 feet or more at what is now the Seattle waterfront, inundating Harbor Island, the South of Downtown district, Duwamish Waterway, and Smith Cove between Queen Anne and Magnolia.

Fires

Fire represents a serious post-earthquake hazard; this is another area requiring additional research and study not addressed by the project team. The loss estimation model generated by HAZUS for the scenario event used by the project team indicates the earthquake will cause about 130 fires, burning structures valued at nearly a half-billion dollars and displacing about 6,000 people.

How serious is the fire hazard? Fire, and not the earthquake, was responsible for much of the devastation of San Francisco in 1906; thousands of buildings that survived the earthquake were lost to the fire. While firefighting techniques and water systems have advanced greatly in the past century, fires posed significant problems following the recent Loma Prieta, Northridge and Kobe earthquakes. Broken gas and liquid fuel lines caused many fires. For example, after the Loma Prieta event, a fuel spill caused a fire at the San Francisco Airport, and gas-fed fires destroyed many homes and apartment buildings. Following the Northridge earthquake, 35 units in a mobile home park burned from a gas leak, and a fire in the science complex at California State University–Northridge was caused by spilled chemicals. In Kobe, extreme traffic congestion, collapsed buildings, and rubble in the streets hampered the response of firefighters to several earthquake-caused major conflagrations throughout the city. Firefighters in each of these communities faced a loss of water due to damaged water systems following the earthquake.

Following a large earthquake on the Seattle Fault, local firefighters would face many of the same challenges as their colleagues have in previous earthquakes – fires in buildings of all types, port facilities and fuel depots from broken natural gas and liquid fuels pipes and spilled chemicals, a lack of water to fight fires, and poor access to fire sites.

Use of HAZUS for Loss Estimation

The project team in developing this scenario used damage estimates and community impacts generated by a computer loss-estimation modeling program called HAZUS, short for Hazards US. The team combined the information generated by HAZUS with current knowledge of structures and development trends to describe the impacts of the scenario earthquake.

HAZUS, developed by the Federal Emergency Management Agency and the National Institute of Building Sciences, used current scientific and engineering knowledge of the effects of earthquakes, information on local geology, national level databases with information on local population, building stock, infrastructure and economy, to produce estimates of damage from the scenario earthquake. HAZUS generated reports and maps that provide information on physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure; economic loss, such as lost jobs, business interruptions, repair and reconstruction costs; and social impacts to people, including requirements for shelters and medical aid.

For this scenario, the project team relied upon a Level 1 analysis, in which HAZUS used default national databases and information to generate its report and maps.

Scenario for a Magnitude 6.7 Earthquake on the Seattle Fault

A major earthquake on the Seattle Fault will have a significant impact on the communities of the central Puget Sound region.

The magnitude 6.7 scenario earthquake and its aftermath will disrupt for weeks and months individuals, families, businesses and governments throughout the region. The disruption will be much, much greater than the February 2001 magnitude 6.8 Nisqually earthquake.

Collapsed buildings or falling debris will kill or injure thousands of people, and trap hundreds of others. Hospitals closest to the fault may be unable to provide care to the injured because of damage to their facilities. Damages to the transportation system will impede emergency responders, prevent many commuters from returning home, and impede traffic and commerce for months. Shelter space for people made homeless because of the quake will be limited in the immediate area because of damage to schools and community centers. Water for drinking and firefighting will be scarce because of pipeline breaks. Power and natural gas service will be out, and telephone and radio communications will be difficult for days. Untreated wastewater will pollute soils and waterways near sewer line breaks.

Losses will be similar in magnitude to those of the 1994 M6.7 Northridge earthquake in California, at $20 – 40 billion, the nation's most costly natural disaster to date.

Scenario earthquake losses include:

- Property damage and economic loss – About $33 billion.
- Deaths – More than 1,600.
- Injuries – More than 24,000.
- Buildings destroyed – About 9,700.
- Buildings severely damaged and unsafe to occupy – More than 29,000.
- Buildings moderately damaged whose use is restricted – About 154,500.
- Fires – About 130, damaging nearly a half-billion dollars in property.

The economic impact of the scenario earthquake on the region and the State of Washington primarily depends upon how quickly the heavily damaged transportation system is placed back into service.

Earthquakes in Washington State

Earthquakes pose a serious threat to life and property in Washington, particularly the Puget Sound region. The most recent damaging earthquake was the 2001 Nisqually event. It caused $2 to 4 billion in damage, primarily from Olympia north through Seattle.

A 2001 study by the Federal Emergency Management Agency found that Washington

Damage to roads, similar to what this Tumwater neighborhood experienced in the 2001 Nisqually earthquake, will be widespread throughout the region close to the rupture in the scenario Seattle Fault earthquake.

has the second highest risk of economic loss caused by earthquakes in the nation, behind only California. Seattle ranks seventh among cities nationwide at economic risk to earthquakes; Tacoma ranks 22nd.

Many residents believe that the Nisqually earthquake is the largest that could hit the Puget Sound region; studies of residential and small business damage after this 2001 event provide confirmation. However, it was not the region's "big one" – an earthquake such as one on the Seattle Fault causing devastating damage and widespread disruption to the region and the state.

The region has a history of large, deep earthquakes of magnitude 6.5 or greater occurring every 30 to 50 years; this includes the Nisqually earthquake. Scientific research in the past 20 years uncovered six active surface fault zones capable of generating much larger, more damaging earthquakes.

One of the region's major fault zones is the Seattle Fault Zone. It runs from Hood Canal in the west, through Puget Sound and south Seattle, and east through Bellevue and Issaquah, roughly parallel to Interstate 90. An earthquake on the Seattle Fault of magnitude 7.3 about 1,100 years ago generated a tsunami in Puget Sound, landslides in Lake Washington, rockslides on nearby mountains, and a seven-meter uplift of a marine terrace on Bainbridge Island.

The six Puget Sound fault zones are of great concern to scientists, engineers, emergency managers, land-use planners and others, because much of the region is heavily urbanized and populated. The three-county study area for this scenario – King, Pierce and Snohomish counties – is home to half the state's population, about half the state's jobs and much of the state's economic base, including nearly all its largest employers, its two largest seaports and its largest airport.

The discovery of these surface fault zones provide much of the reason scientists believe the earthquake threat in Puget Sound is much more significant than thought just a few years ago.

The Scenario Earthquake

Evidence of an earthquake discovered in a trench in Vasa Park in Bellevue is the model for the scenario event. The scenario earthquake has a moment magnitude of 6.7. The fault ruptures or breaks the surface for a distance of about 14 miles, from Harbor Island in the west to an area east of Lake Sammamish, passing through Seattle, Mercer Island, Bellevue, and the Issaquah area. The rupture

Comparing the scenario Seattle Fault earthquake with other recent major earthquakes

Earthquake	Damages	Est. loss (2004 $)
Seattle Fault scenario event – M 6.7 Shallow quake, with fault rupture at surface in Bellevue	Projected: 1,660 dead, 24,200 injured. 9,700 buildings destroyed, 29,000 buildings severely damaged and unsafe to occupy, 154,500 buildings moderately damaged with use restricted. 130 fires burn. All six major highways experience partial closures lasting months due to substantial damage, collapsed bridges. Utilities cut in areas with poor soils. Port facilities badly damaged, use restricted. Operations of businesses relying on "just-in-time" deliveries disrupted by collapsed supply warehouses, transportation closures, communication outages.	**$33 billion**
Nisqually, 2001 – M 6.8 Deep quake at 36 miles depth, NE of Olympia, WA	One death, 320 injured. Most severe damage found in downtown Olympia, Pioneer Square and SODO districts in Seattle. Legislative Building, SeaTac Airport control tower, Boeing Field runways, and Alaskan Way Viaduct seriously damaged. Highway damage minor. Power outages repaired within a day.	**$2 – 4 billion**
Kobe, Japan 1995 – M 6.9 Shallow quake at 8.7 miles depth, fault ruptured into downtown Kobe *The first severe earthquake to strike the center of a modern city in a highly industrialized country.*	More than 6,230 deaths, 40,000 injured. 102,000 buildings destroyed. 300 fires burned 7,000 buildings. 300,000 people homeless. Many important public facilities damaged or collapsed, including City Hall, several hospitals, 85 percent of schools. Widespread utility outages and failures. Major highways, bullet train networks badly damaged, service cut. Much of seaport inoperable, many shippers moved operations, did not return after repairs made. Manufacturing seriously disrupted.	**Up to $200 billion**
Northridge, 1994 – M 6.7 Shallow quake at 10.3 miles depth, beneath San Fernando Valley NW of Los Angeles, CA	57 deaths, 9,000 injured, 22,000 people homeless. 7,000 buildings severely damaged, unsafe to occupy, 22,000 buildings moderately damaged, use restricted. Nine hospitals closed. Eleven major roads into Los Angeles closed due to collapsed bridges, interchanges. Some utility failures and outages. Time of earthquake – 4:31 a.m. – prevented greater loss.	**$40 billion**
Loma Prieta, 1989 – M 6.9 Shallow quake at 10.5 miles depth, NW of Santa Cruz, CA	62 deaths, 3,000 injured, 12,000 people homeless. 18,300 homes and 97 businesses destroyed. Transportation system badly damaged – I-880 collapsed in Oakland, deck of Oakland Bay Bridge collapsed, and Embarcadero Freeway nearly collapsed. Power outage left San Francisco dark for first time since 1906 EQ. Several public buildings badly damaged. 27 fires burned. Tourism industry hurt.	**$9 – 15 billion**
Olympia, 1949 – M 6.8 Deep quake at 33.5 miles depth, NE of Olympia, WA	Eight deaths. State Capitol Campus buildings badly damaged. 40 percent of Chehalis damaged. Public utilities seriously damaged, services interrupted. Landslide generated tsunami in Tacoma Narrows.	**$0.2 billion**

Note: Figures rounded to the nearest billion and adjusted to 2004 dollar values.

raises the level of the ground surface on the south side of the fault by about 6.5 feet.

Ground shaking will be severe, much greater than experienced during the 2001 Nisqually earthquake. Damage will be far worse and more extensive than seen in any earthquake in the state's history.

Areas closest to the fault rupture, as well as areas of poor soils such as river valleys and steep slopes, will experience strong ground motions and the greatest damage. These areas include the Duwamish River-Green River Valley, Issaquah Creek Valley, Sammamish River Valley, Snoqualmie River-Snohomish River Valley, Puyallup River Valley, and the shorelines of Puget Sound, Lake Washington, Lake Union and Lake Sammamish.

Damage to homes, warehouses, and those housing small businesses will be widespread throughout the region. Damage to taller buildings such as central business district high rises and large-span bridges, while still significant, will be concentrated in areas closer to the fault rupture.

Impacts of the Scenario Earthquake

Immediately After the Quake

The scenario earthquake badly damages homes, office buildings, manufacturing plants, schools, port facilities, utilities and transportation routes from the south end of downtown Seattle east through Bellevue and throughout river valleys north and south of the cities. Collapsed structures and highway bridges kill or injure thousands of people. Communication links are swamped or broken, making communications difficult if not impossible throughout the region. Police, fire, and medical aid units receive hundreds of calls for help, but clogged and damaged roadways limit their ability to respond. Areas closest to the fault rupture are devastated. As the initial response gets underway, mayors, city and county councils, and state officials consider the implications of the disaster decisions on rebuilding and restoring the well-being of their communities.

Among the biggest concerns facing the region immediately after the earthquake are that:

- Police, fire, and medical aid units will be overwhelmed in the initial hours after the earthquake.
- Damage to transportation systems will make movement of people and freight around the region difficult for weeks or months.
- Demand for emergency shelter, food and water by displaced individuals and stranded commuters will place tremendous demand on available community resources.
- Disruptions to transportation, telecommunications, and utility systems, and damage to key facilities will complicate the daunting task of getting the region – and the state's – economy back on its feet.

The scenario earthquake will overwhelm the fire, rescue, and emergency medical services responders of the Central Puget Sound region.

Calls to public safety agencies for help will increase dramatically. Damage to vehicles and facilities, injuries to personnel, and damage to roads and bridges will affect response times of firefighters, police officers, and emergency medical staff. Public safety radio systems will be overloaded, making communication between dispatchers and responders, and between responders, difficult.

Initially, responders address high priority problems to keep them from escalating.

Emergency medical responders must adjust standards of care for the injured; it may become necessary to deliver hospital-like care from temporary facilities until air or ground transportation can take patients outside the area.

Availability of water is a key concern. The earthquake will trigger fires that burn nearly a half-billion dollars of property near the fault, and a lack of water will hamper firefighting. One third of the region's households and businesses will lose water service. Restoring service as quickly as possible is important to sustain human life, for sanitation, for business and industry, and for firefighting.

Caring for the injured will be difficult because of a shortage of health care services. A lack of supplies and inability of staff to get to hospitals and clinics will compound damage to facilities. The lack of health care services will be significant not only in central Puget Sound, but also to people from adjacent states and Alaska who travel to the region for care because of expertise in specialty areas such as cancer care and organ transplantation, for example.

Communities will face significant problems providing emergency shelter to thousands of individuals and families with badly damaged homes and to commuters unable to return home. Many communities use schools as emergency shelters, but about 40 percent will be unusable because of damage.

Hundreds of thousands of commuters will have difficulty returning home because of damage to key transportation corridors and a lack of alternative routes. Detours will be available, but the commute will be many hours long and very slow for those able to leave. Ferries will use undamaged landings outside of the immediately impacted area; movement of ferries to other landings will strand walk-on ferry commuters in downtown Seattle.

A number of groups will require special attention and pose challenges to responders immediately after the earthquake. These include schoolchildren, the disabled, retirees, and non-English speaking people.

The earthquake will badly damage vulnerable schools and injure hundreds of children and adults. Damaged schools will be unavailable for an extended period. Districts must find ways to accommodate a significant population of displaced students, by busing them to undamaged schools further away from home, double-shifting classes, or through other means. Communities who rely on schools for shelters and staging areas will have to look to community centers and other facilities.

Disabled people and senior citizens require special attention because of their special needs. Many do not work, have medical conditions requiring regular medication or therapy, and they tend to live in older or substandard housing more likely damaged by the earthquake.

In previous events of community-wide impact, culture and language barriers led to confusion about what was happening and how people should respond. This earthquake will be no different. The central Puget Sound region is home to substantial populations of people that do not speak English as their primary language. One area badly damaged by the scenario earthquake is Seattle's International District, the cultural and commercial center for the region's Asian American and Pacific Islander communities.

Communities will have difficulty dealing with multiple environmental problems caused by the earthquake. Release of hazardous materials from factories, transfer and storage sites, and overturned trucks and trains will generate fires and explosions, cause human health hazards, and pollute the air, water, and soil. Untreated wastewater will spill in areas where major sewer lines break, or into Elliott Bay if treatment plants lose power.

Deciding whether homes are safe to remain in will be the focus of individuals and families immediately after the earthquake, which will displace about 46,000 households. Displaced people will live with other family members or relocate to temporary shelters. Family members scattered throughout the region will not be able to communicate or find one another with telephone services unavailable.

Families able to remain in their homes may not have power for lights and cooking, natural gas for heat and cooking, water for drinking, cooking and sanitation, or phone service for keeping in touch with family and friends for some time after the earthquake.

The psychological impact of the earthquake will be significant. Aftershocks, some strong and causing more damage, will rattle nerves and injure more people. Post-disaster stress will continue for months for some people, heightened by the death or injuries of a loved one, temporary relocation, making repairs to homes, and replacing cherished items and household goods.

Loss of life and housing pose the largest social burdens, as people struggle to rebuild their lives. Temporary and long-term housing arrangements will disrupt lives and may force people to relocate permanently outside of their neighborhood or community. Temporary or permanent closures of community centers, churches, schools, interest groups and social clubs will stress the community's social fabric.

The earthquake will most affect those people with the fewest social and economic resources; they will have more difficulty recovering from the event. Moreover, many of the elderly, the disabled and non-English speakers have special needs and may be more reliant on social networks and government and charity services during the recovery process.

Personal and financial stress and anxiety resulting from disruptions at home, work, school, and daycare may result in higher incidence of social and psychological problems, such as increased absenteeism, alcohol or drug abuse, and physical abuse.

Resources to help individuals and families recover from a major disaster such as the scenario Seattle Fault earthquake are limited. Most people incorrectly believe that the federal government will repay them fully for their damages and losses. Few have earthquake insurance or the savings to cover their expenses for an extended period. Government assistance following a disaster is limited to uninsured losses only. Credit-worthy individuals and families initially will be steered into low-interest loan programs. Those who do not qualify for these loans will receive grants to help repair damaged homes and take care of immediate needs. Disaster grants target those with lower incomes, but some in greatest need will not apply due to cultural issues or mistrust of the government.

The potential is great for individuals and families unable to carry the financial burden of their losses to relocate to another area, possibly with other family members.

Economic Impacts

Major urban earthquakes can cause economic loss in the tens of billions of dollars. The impacts of the scenario Seattle Fault earthquake extend beyond the cost of repairing shattered buildings and broken freeway bridges to lost business output and productivity, business failures and loss of competitiveness in the national and global marketplace.

Perhaps the most critical economic restoration initiative facing the region is repair of damaged transportation systems. A key lesson from the Northridge, Kobe, Japan and Nisqually earthquakes is that damaged transportation and utilities infrastructure cause major economic disruption.

The 1994 Northridge earthquake was a moderate-sized event, but the costliest natural disaster in U.S. history. Small businesses – particularly those that rented rather than owned their space – were most vulnerable to long-term economic hardship or failure. Damage to transportation systems was as great a source of disruption as building and infrastructure damage; one quarter of business interruption loss was due to transportation disruption. Losses in the Los Angeles area would have been greater if not for the region's redundant freeway network – a redundancy not found in the Puget Sound region.

Following the 2001 Nisqually earthquake, small businesses in highly impacted areas were most economically vulnerable. Damage to roads, bridges and buildings made it hard to conduct normal business in some locations for months; damage to local airports caused significant impacts to aviation-related businesses that lasted for weeks.

Kobe's experience provides the best example of what to expect following the scenario Seattle Fault earthquake. This 1995 earthquake was the world's first experience of a large earthquake striking a modern urban economy. Economic sectors in decline before the earthquake were vulnerable to structural change that accelerated after the event. For example, the Port of Kobe's ranking among world container ports dropped from number 6 to number 17 after the disaster. It took two years to repair the port and the region's transportation systems; this resulted in cargo traffic cut in half as shippers moved permanently to other ports outside the disaster area. The same thing happened to the Port of Seward following the 1964 Great Alaska earthquake; much of Seward's business went to the Port of Anchorage.

Similar infrastructure vulnerabilities will yield serious economic disruption in the Puget Sound region from the scenario earthquake.

Small businesses are more vulnerable to failure than large ones because they have fewer resources and are less likely to have prepared or planned for such an event. Marginally successful businesses will find the earthquake is the straw that breaks their financial backs. Strong businesses will fail if the earthquake hits at a moment when they are vulnerable. Businesses whose customer base is significantly disrupted may not recover.

Outages of electric power, water, sewers, and natural gas will contribute to the economic disruption. While these outages will be of shorter duration than transportation disruptions, they will affect large areas, including those with little physical damage. In two recent disasters – the 1999 Chi-Chi earthquake in Taiwan and the 1993 Great Midwest Flood in Des Moines, Iowa – utility and transportation disruptions caused greater loss of revenue and business than the actual ground shaking or flooding.

The most immediate and widespread business disruptions will result from concerns for life and safety. Many businesses will stop operations to assess structural damage and determine the condition of their employees and building occupants. Transportation disruption will affect employees, suppliers, and customers; even if buildings or alternative operation centers survive, such facilities are worthless if personnel, suppliers and customers cannot reach them.

Most businesses use just-in-time inventory practices. Limited on-site inventories and disruption to suppliers and supplies will limit functionality even of businesses that suffer no damage. Many neighborhoods and markets will not have access to goods and services because of poor transportation. Given small inventories on hand at the time of the earthquake, residents around the region will have trouble securing basics such as groceries and prescriptions.

Interrupted power and communications will leave most small- and medium-sized businesses unable to function. Small banks will not be able to obtain the cash needed for recovery. Major banks will continue operations, but branch

Repair of damaged transportation systems will be the most critical economic restoration initiative facing the Central Puget Sound region after the scenario Seattle Fault earthquake. The quicker transportation systems are repaired, the quicker the region will recover from the earthquake.

offices, automated teller machines, and electronic banking may not.

Also important will be worker fear of reoccupying damaged buildings and a greatly reduced capability to assess damaged structures. The lack of assessment capability will interrupt business operations throughout the region.

Economic revitalization planning will be critical to the future of affected communities and the region. The scenario earthquake will create a new future that will not include many local and regional businesses. Businesses without large cash reserves will not survive. Corporate money and highly trained workers could leave. A significant number of unrepaired buildings will give the appearance that a neighborhood is abandoned. Neglected structures will affect significantly the long-term economic viability of area businesses, and on neighborhood safety and crime.

Physical Damage

Ground Failures

Significant ground failures – including liquefaction and landslides – will occur throughout the region and contribute greatly to building damage.

Buildings on soils that liquefy will settle or tip. Liquefaction-induced settlements, sinkholes, and sand boils will disrupt pavement, such as occurred during the 2001 Nisqually earthquake at the King County International Airport.

Buried structures such as fuel tanks and power vaults within liquefied soil will become buoyant and rise toward the ground surface. Water ejected from sand boils could cause localized flooding. Street and basement flooding from liquefaction occurred in Puyallup during the 1949 Olympia earthquake.

The Nisqually earthquake caused about a hundred landslides throughout the Puget Sound region; the number would have been much greater if rain water had saturated soils. The scenario Seattle Fault earthquake will cause thousands of landslides over a wider area because it is shallower and its ground shaking much greater than the Nisqually event. Landslides along shorelines will generate local tsunamis as land masses rapidly slide into the water, or as underwater land masses move down slope.

Utilities

Outages of electricity, water, waste water collection and treatment, natural gas and liquid fuels, and communications will last from days to weeks depending upon a variety of factors including location of facilities to the fault rupture, ground shaking, and soil strength. Loss of utilities means some homeowners throughout the region will not have lights, heat, fuel for cooking and vehicles, water for drinking and sanitation, and communications with family and friends, for varying amounts of time. Implications for affected business operations are similar.

Few water facilities will resist the large ground motions expected in close proximity to the fault rupture. Many tanks close to the fault rupture will rip loose from their anchorages, some will burst open. Support facilities will become non-functional. North-south trunk lines will break at the fault rupture. Several thousand pipeline failures will occur. It will take weeks to restore service to areas where liquefaction causes heavy damage to old cast iron piping – the Duwamish Valley, the Sammamish Valley, and as far south as Renton and Kent. The community with the most tenuous water supply is Mercer Island, dependent on pipelines that parallel the Seattle Fault.

King County’s wastewater treatment plants at West Point and Renton are vulnerable to the earthquake’s ground motions, which will be larger than both plants can resist. Highly liquefiable soils in valleys will float or move sewer lines, with broken pipes spilling untreated sewage into both Lake Washington and Lake Sammamish as well as into the Green River. It will take weeks to complete repairs to some large diameter sewer lines.

The region’s electrical power generation, transmission and distribution system is robust and redundant. Its most vulnerable points are high-voltage substations, many with unique components that can take months to replace if damaged. Most areas experiencing outages will have power restored within 72 hours. Outages will last for weeks in areas with heavily damaged critical substations. A critical link in Seattle’s power infrastructure is the Alaskan Way Viaduct, which carries a combination of transmission and distribution lines running along and beneath the structure. The viaduct will be heavily damaged or collapse in the scenario earthquake, causing significant damage to these power lines.

Telecommunication systems performance is mixed. The wired phone system will perform well. Most switching centers are highly reliable and robust. Emergency power is common; loss of water for cooling switching center computers will be a problem. Wireless phone systems are less robust, built with less attention to reliability because of the highly competitive business environment. Many wireless facilities do not have emergency power. As a result, wireless phone service will not be dependable for a time following the earthquake. Natural gas systems will perform well. Welded-steel high-pressure transmission lines are in competent soils along most of their route south from Canada through the region. Pipeline alignment is at the eastern end of the fault rupture; if limited fault displacement occurs, these lines should perform well. Much of the region's gas service is through an intermediate and low-pressure distribution system which has seen most of its cast iron pipe replaced in recent years with more damage resistant plastic pipe. Some damage will occur in the distribution system, particularly in areas of poor soils such as river valleys north and south of the fault.

The Olympic pipeline provides liquid fuels such as gasoline and jet fuel from refineries in Northwest Washington. It runs beneath residences, schools and churches throughout the region. Although specific vulnerabilities of the pipeline are not known, the risk of failure or release of liquid fuels is highest where it passes through areas of landslide-prone or liquefiable soil. The pipeline crosses the Seattle Fault in an area where the scenario earthquake will create several feet of displacement and where liquefiable soils exist. If the pipeline ruptures, it will spill thousands of gallons of fuels that could pollute soils and nearby creeks, and catch fire. A 1999 rupture of the pipeline in Bellingham spilled a quarter-million gallons of gasoline that caught fire and killed three people. It is more likely that broken valves at a distribution center south of Seattle, where fuel is loaded into trucks for local gas stations, will cause spills and fires.

Transportation

The scenario earthquake will inflict serious damage to the region's transportation systems – roads and bridges, airports, waterfront facilities, railroads and ferries. Damage will be widespread near the fault rupture, and in areas of liquefiable soils or slopes vulnerable to landslide.

All six major freeways – Interstates 5, 90 and 405, and State Routes 99, 167 and 520 – experience partial closures lasting for months or years due to major damage that includes collapsed bridges and elevated freeways. These routes carry more than 600,000 vehicles per day. A well-placed accident can shut one of these routes down for hours during the normal daily commute, forcing commuters onto other routes.

Following the earthquake, much of the traffic these freeways carry will move onto surface streets. Severe traffic congestion will occur for at least a year. Commutes to work that took 30 minutes before the earthquake could take hours. For example, the day after the 2001 Nisqually earthquake, a five-mile commute from West Seattle to downtown Seattle took two hours because a safety inspection temporarily closed the Alaskan Way Viaduct. Movement of goods from ports to warehouses to final destinations – manufacturers, retail outlets, and hospitals, for example – will be much slower, with more deliveries scheduled during the night when congestion will be less.

Airports including Seattle-Tacoma International Airport close immediately. Renton and King County (Boeing Field) airfields will experience significant liquefaction to their runways. It will take several days for them to re-open to limited traffic and a month to open to 80 percent traffic. Sea-Tac will reopen more quickly because damage to its runways will not be significant, although damage to terminal facilities will slow operations for a time.

Damaged port facilities will be out of service for months or years due to damage caused by ground failures along the waterfront. Half of Harbor Island may slide into Elliott Bay, reducing capacity of the Port of Seattle. A wave generated by the landslide will pound other shore-side facilities in the bay. Damage caused by other large soil movements will limit access to container terminals. Cranes at container terminals will be damaged or topple, and utilities will be disrupted. In many cases, docks will be of very limited use, except as temporary berthing for emergency supply ships, until damaged piling are replaced and access restored. Because of extensive damage to port facilities in the region, many shippers will move their operations to undamaged facilities; some will not return for years, if ever.

Seattle-based ferry routes will shut down for at least a week, with vessels rerouted north and south to undamaged landings to help with post-earthquake emergency transportation. Damage from ground failures and failure of the seawall will close Seattle and Fauntleroy ferry terminals. Significant damage to the vessels is unlikely. Temporary equipment and facilities will help ferries move passengers and vehicles around blocked land routes. Ferry service should reach 90 percent capacity within nine months.

Railroads move more than 200,000 tons of freight in and out of the region every day, along with thousands of long-distance passengers and short-haul commuters. The earthquake will shut down rail operations until inspections and repairs are complete to ensure safety of the tracks and associated facilities. Rail lines close to the seawall in Seattle will distort and become unusable. Landslides and severe ground shaking will derail freight, passenger or commuter trains where rails run below slopes or in areas of poor soils; landslides could sweep trains into Puget Sound. Undamaged lines will return to service within hours, while lines with minor damage will return to operation with speed restrictions. In cases of major track damage, temporary repairs will allow restricted operation; liquefaction-induced damage will take a week or longer to repair. Damage to rail yards, container and trailer handling facilities, passenger stations, and locomotive and car servicing facilities will take weeks to repair and transfer some operations to alternate, less convenient locations. The increased cost of rail operation with damaged facilities and lost revenue during the recovery period could exceed the cost of repairs.

Buildings

Modern structures built on firm soils will survive with various degrees of damage in the scenario earthquake. Unretrofitted, older structures will sustain heavy damage. Of particular concern are unreinforced masonry and reinforced concrete tilt-up structures, which have performed poorly in past earthquakes and are common in the Puget Sound region. The most extensive damage will be along the Seattle Fault rupture and along low-lying river valleys with liquefiable soils.

Unreinforced masonry (URM) buildings will perform poorly. Most of these buildings predate 1940 and the use of modern construction techniques and materials. There are about 2,200 URM buildings within the region; the largest concentration is in the Pioneer Square and International District neighborhoods of Seattle near the fault rupture. URM building damage was common during each of the last three significant earthquakes in western Washington – 1949, 1965, and 2001. Unless seismically retrofitted, most URM buildings close to the fault rupture or in poor soils will sustain extensive damage or collapse, resulting in significant economic loss, injuries, and loss of life. Moderately damaged URM buildings in historic districts will present additional challenges to historic preservation boards during the recovery period.

Pre-1973 reinforced concrete tilt-up structures are another class of structures highly vulnerable to the scenario earthquake. Constructed in the region since the 1950s, the industrial area south of downtown Seattle is home to the majority of older tilt-up buildings. The expansion of tilt-up construction followed population growth into the suburbs and throughout the central Puget Sound region. These structures primarily house light industrial and manufacturing facilities, supply warehouses, and retail stores. Many tilt-up buildings in low-lying areas near the fault rupture will partially collapse; those located along river valleys in Bothell, Redmond, Kent, and Auburn will suffer similar damage.

Performance of low- and mid-rise structures depends upon their age, construction type, location, and soils. Structures built before 1970, unreinforced masonry buildings and pre-cast reinforced concrete parking structures are most vulnerable to damage. Extensive damage will close indefinitely half or more of the businesses, offices, restaurants, and retail in these buildings in the South of Downtown District, International District, Pioneer Square, and along the Elliot Bay waterfront. Newer retail and office structures will close for two to four weeks, primarily due to less damage and a lack of utilities. Damage to low- to mid-rise structures and building closures in other areas of the region will be a function of distance from the fault rupture and whether they are in areas of severe ground shaking or on liquefiable soils. For example, more than half of these structures in Renton, Kent, Auburn, Sumner and Puyallup will experience extensive damage because of soil liquefaction. Businesses in low- to mid-rise structures in Mercer Island, Bellevue, and Issaquah's Old Town will close for up to a month for inspections and repairs.

High-rise buildings in Seattle and Bellevue central business districts will experience very strong ground motions, exceeding levels recorded in downtown San Francisco and Los Angeles during the 1989 and 1994 earthquakes, respectively. Nearly all high-rise buildings in Seattle and Bellevue will have visible structural damage and shattered windows, with about half of the pre-1975 high-rise building stock extensively damaged; collapse of a few older buildings is expected. Nonstructural damage will be widespread. Damage will be less in high rises in Tacoma and Everett central business districts due to less severe ground shaking there.

About one-third of residential structures in areas of severe ground shaking will be extensively damaged and unsafe to occupy. The most significant impact on residential structures will be structural damage, such as collapse of unretrofitted unreinforced masonry buildings and buildings with large openings at ground level. Unanchored structures will slide off foundations, and masonry chimneys will collapse and fall onto homes. Ground failures will damage foundations. Nonstructural damage will be common; broken gas pipes will create a fire hazard, and fractured water pipes will result in loss of potable and firefighting water supply.

Structures of some industrial facilities predate modern seismic design, and many are in areas subject to liquefaction-caused damage. Vulnerable facilities will experience structural damage, loss of manufacturing equipment, prolonged downtime, loss of production, and loss of market share. Facilities within a mile or two of the fault rupture have a high probability of experiencing at least moderate damage, as will more distant facilities on poor soils. Damage to industrial facilities resulted in indirect losses in previous major earthquakes; such impacts include release of hazardous materials, which can have long term environmental effects.

Essential Facilities

Hospitals care for patients from Washington and Alaska, and provide specialty care to patients from throughout the nation. Harborview Medical Center in Seattle is the state's only Level I trauma center. Immediately after the scenario earthquake, the central Puget Sound region will have a shortage of hospital capacity because of damage to facilities and increased demand. Structural damage will vary depending on the building type, age of construction and building location; much of the damage will be nonstructural, consisting of dislodged equipment, broken pipes and ducts, fallen ceilings, and water damage from sprinkler systems.

Field hospitals will care for some of the injured on a temporary basis. Hospitals will rapidly reconfigure their facilities and operations to provide continuity of care. Staff will triage patients to focus on the highest medical needs and establish special care areas to provide services outside of the traditional patient room. Essential staff will extend their shifts and use in-house lodging until replacement staff arrives. Hospitals will delay non-essential or elective procedures until resuming normal operations and restoring staffing levels.

The loss of essential utilities such as power, water, sewer, and city-supplied steam and of just-in-time delivery of medical supplies, gases and pharmaceuticals will impede the ability of the hospitals to sustain safe operations.

Fire station performance during the scenario earthquake will depend on the level of ground motion at the station location and the age of the structure. Fire stations most at risk are those stations that are older, closest to the fault rupture, or in poor soils. This situation poses a significant challenge to post-earthquake response and suppression of fires given that these areas will experience the highest level of damage and pose greatest demand for service. Delaying response will be digging out of apparatus trapped in damaged stations and unavailability of some units because of damage. Fire stations with heavy structural damage will be unusable. Units returning to these stations will be homeless, requiring temporary quarters for apparatus and personnel while still providing for timely response within a specific area.

Most of the region's police stations are relatively modern construction or seismically retrofitted. Police stations in smaller cities, however, are located in city halls typically not designed as essential facilities. Police response following the earthquake depends on deploying officers to the field. Performance of the transportation infrastructure is important to overall performance of police response; damage to major bridges and roadways will hamper police response significantly.

Schools, typically not considered essential facilities, have unique characteristics that set them apart. School buildings have one of the highest occupant densities of any building type, and society places a high value on protecting children. Communities also look to schools for temporary shelter and distribution points for emergency supplies following disasters. Until the Nisqually earthquake, schools sustained a disproportionately high level of damage from previous earthquakes primarily because of their age, design and construction materials used. Damage to school buildings from the Nisqually earthquake was limited because of ongoing seismic strengthening, non-structural mitigation, and the number of schools built in recent years to modern building codes.

The scenario earthquake will cause the greatest damage to unretrofitted older schools and buildings on poor soils. Immediately after the scenario event, schools will have difficulty sheltering and feeding children, and connecting them with parents; many parents will be unable to reach schools to pick up their children immediately after the earthquake. Schools with slight to moderate damage will be repaired and useable within a few days or weeks; those with extensive damage will be demolished and rebuilt.

School districts will restart classes as quickly as possible. Temporary solutions include busing students to repaired or undamaged schools, some far from home. Crowded schools will double-shift students and bring in portable classrooms as space allows. Districts will use facilities such as community centers and churches as temporary schools, and explore on-line teaching after restoration of telecommunications systems.

Also of concern is the Seattle campus of the University of Washington. Daily, the university is home to 39,000 students, 23,400 faculty and staff, and hundreds of visitors and patients in hospitals and clinics. The university, one of the top research institutions in the nation, has significant holdings of irreplaceable research and research specimens in laboratories, as well as valuable artifacts in museums and art collections. The average age of the university's buildings is 43 years; some seismic strengthening has taken place in recent years. While the campus is outside the area of greatest ground shaking, the impact of the scenario earthquake could cause serious damage to buildings and infrastructure and compromise the university's ability to function as an educational and research institution.

Call to Action

Priority Recommendations

1. Establish a funded state-level seismic safety board or commission, reporting directly to the Governor to recommend polices and programs to reduce the earthquake risk in Washington.
2. Identify critical public facilities statewide that have a high seismic risk and establish long-range plans to improve their safety in an earthquake.
3. Develop local and state funding and legislation requiring mandatory seismic retrofits of high-risk buildings, such as unreinforced masonry and tilt-up structures.
4. Establish and implement a strategy to quicken the pace of protecting seismically vulnerable critical transportation infrastructure.

Other Recommendations

1. Continue to expand and improve information and maps on earthquakes and related geologic hazards, and require their use as best available science for state building codes, local land-use planning and development decisions, and local and state emergency response, recovery and continuity plans.
2. Develop financial and other incentives to increase the level of seismic safety in public and private buildings through structural and non-structural mitigation measures.
3. Develop innovative programs to educate the public, public agencies, and the business community that both appropriately communicates the risk posed by earthquakes and generates action by individuals and organizations so they are self-sufficient for at least 72 hours following an earthquake.
4. Provide adequate funding to upgrade the region's seismograph network to make it more robust and to enhance its capabilities.
5. Establish an earthquake information clearinghouse to improve access to best available science and best practices for earthquakes and related geologic hazards in Washington for the public, government agencies, businesses and other organizations.

Chapter 9

A Call To Action

Contributors

The Seattle Fault Earthquake Scenario Project Team

The Seattle Fault Earthquake Scenario created a unique opportunity to draw on the knowledge and advice of many of our region's experts in the fields of earth and life sciences, earthquake engineering, planning and emergency management. The multi-disciplinary project team developed a broad, unbiased look at the Puget Sound region's and the State of Washington's vulnerability to one of their top earthquake threats – the Seattle Fault. The recommendations that follow represent only the beginning of a conversation to reinvigorate and continue to improve our state's resilience to earthquakes and other hazards that could lead to disasters. We have an opportunity to act. The time to act is now.

The Seattle Fault Earthquake Scenario provides a forward-looking assessment of a real and credible earthquake threat in the Puget Sound region. A multi-disciplinary team of engineers, planners, geologists, seismologists, economists, and emergency managers spent thousands of hours examining for the first time the implications of a major earthquake on the Seattle Fault. They used state-of-the-art earthquake hazard assessment tools and information on development and development trends in analyzing and evaluating the hazard posed by the scenario earthquake, and estimating the life-safety and socio-economic risks to our region. The 3 Ds of disaster – Deaths (more than 1,600), Dollars ($33 billion in direct and indirect costs), and Downtime (months to years for recovery of the impacted region) – are significant for this event.

This earthquake project provides a focal point to help raise the level of awareness of the region's earthquake threat and on discussions on how to reduce its vulnerability. It applies a combination of best available science with an infusion of best available multi-disciplinary knowledge to the complex problem of reducing our region's earthquake vulnerability while improving our region's preparedness. It is written in straightforward terms so the region and state's elected officials, business owners, lifeline managers, first responders and emergency managers, and the design, construction and building safety community have the best information available on the region's top earthquake threat.

Now is the time to act. We cannot wait for the next big devastating earthquake, which could be in the Western United States or perhaps Western Washington, to remind us to act. We already have had three reminders during the last 55 years in Puget Sound – in 1949, 1965, and again in 2001. Three times, we have experienced damaged schools, bridges, and airports. Three times, we have seen the fate of unreinforced masonry buildings from Olympia to Seattle. Three times, we have seen businesses experience significant downtime and disruption. But these local reminders pale in comparison to the dangers of the Seattle Fault.

During the past 25 years, significant advancements have improved the awareness and understanding of the region's earthquake vulnerability. Seismic mitigation programs in our state have improved the earthquake performance of certain infrastructure and reduced risks to the public. However, regional and state leaders must use this opportunity to not only continue existing efforts but also to reinvigorate past efforts that have stalled. New seismic risk reduction programs and directives – derived from the hard lessons learned from the significant earthquake losses experienced by neighboring states and Seattle's sister city Kobe, Japan – are needed. There is much to accomplish. The time to act is now.

The Seattle Fault Earthquake Scenario Project Team respectfully presents the following recommendations as a call for action by regional and state elected officials. Four recommendations are Priority Recommendations, meaning they are the steps that require first consideration by policy makers.

Priority Recommendation No. 1

Establish an Independent State Seismic Safety Board or Commission

Establish a funded state-level seismic safety board or commission, reporting directly to the Governor to recommend policies and programs to reduce the earthquake risk in Washington. Specifically, the board or commission would have the following roles:

- **Planning** – Develop an Earthquake Loss Reduction Plan for the state based on the best available science of the earthquake threat.
- **Coordination** – In concert with the State Emergency Management Division, facilitate coordination of earthquake-related programs for agencies at all levels of government and with non-governmental organizations. This includes, where practical, coordinating earthquake loss-reduction activities with other loss-reduction programs such as homeland security.
- **Legislative Advisory** – Propose legislative initiatives related to seismic safety, review all seismic related bills presented to Congress, the state Legislature and local government, and develop recommendations to the Governor.
- **Implementation** – Monitor implementation of the State's Earthquake Loss Reduction Plan, and support implementation of the State's Enhanced Hazard Mitigation Plan.
- **Public Education** – Facilitate coordination of public education programs to improve understanding of seismic safety issues by governmental bodies, private companies, organizations, and citizens.

Rationale:

Washington has the second highest earthquake risk in the nation, behind only California. The Federal Emergency Management Agency projects the long-term average economic loss to Washington from damage and lost income due to earthquakes is more than $228 million annually. The probability of strong ground motion and the economic consequences of that ground motion underpin this annual loss estimate.

Currently, a number of state and local agencies have earthquake loss-reduction efforts underway. These inadequately funded efforts focus on public education and are poorly coordinated with other similar loss-reduction activities. For example, the State's Earthquake Program has $112,050 available for state fiscal year 2005, primarily for public education. The State of Washington and local governments have developed natural hazard mitigation plans, but many of the mitigation strategies identified in the plans are for hazards other than earthquake and most of the strategies are unfunded. Federal mitigation programs provide the state with grant funding following disasters – the state had $26 million following the 2001 Nisqually earthquake – but requests ($72 million) far outstripped availability of funds.

Washington has had a number of committees working on seismic safety issues since 1990, all of which developed recommendations to reduce earthquake losses. However, none of the committees – including a subcommittee of the Governor's Emergency Management Council, which provided seismic safety recommendations to the council in early 2004 – has had the authority to implement loss reduction actions.

Without an independent state seismic safety board or commission to develop a comprehensive statewide loss reduction strategy, there is less likely to be:

- Identification of the most vulnerable elements of transportation and lifeline networks, which have many owners, both public and private.
- A timely fix of major identified seismic vulnerabilities.
- Coordination of efforts between local and state agencies doing similar work.
- Increased awareness of the earthquake risk.
- New laws necessary to protect the lives and property of state residents from earthquakes.

California and Oregon created seismic safety commissions. California's Seismic Safety Commission, formed in 1975, is the oldest and most well-organized commission. Since its inception, this commission helped establish uniform seismic risk reduction strategies and furthered a wide variety of earthquake initiatives in California, ranging from legislation requiring retrofit of unreinforced masonry buildings to urban search and rescue. Some of these initiatives have served as seismic risk reduction models for communities around the world. Oregon's Seismic Safety Policy Advisory Commission, formed in 1991 to promote earthquake awareness and preparedness through education, research and legislation, has influenced that state's seismic program and codes. The advocacy of Oregon's commission spurred development of a package of bond issues to support seismic upgrading of critical structures such as hospitals, fire and police stations, public schools, community colleges, and the higher education system, approved by Oregon voters.

Not forming a seismic safety board or commission in Washington will result in the continuation of poorly funded, low-level, low-effort, earthquake loss-reduction activities of existing organizations.

Priority Recommendation No. 2

Implement Risk Reduction Plans for Critical Public Facilities

Identify critical public facilities statewide that have a high seismic risk and establish long-range plans to improve their safety in an earthquake. Such facilities include hospitals, schools, and police, fire and other critical infrastructure important for emergency response and long-term recovery. These facilities represent vulnerability to high loss of life or collateral loss such as reduced response capacity.

Implementing this recommendation requires coordination with ongoing homeland security risk-assessment efforts, to include:

- Adoption of a consistent methodology for conducting facility assessments.
- Assessment of public agency buildings and identification of seismically vulnerable facilities.
- Development of mitigation strategies to reduce earthquake losses to at-risk critical facilities.
- Identification of funding sources and possibly legislation to implement the strategies.

Rationale:

Without mitigation strategies to reduce the earthquake risk of critical public facilities, there will be more casualties in at-risk buildings, a reduced capacity to handle casualties and people made homeless, and an increase in response and recovery times. Damaged hospitals, for example, may have to turn away earthquake victims and possibly relocate existing patients.

To date, there has not been a comprehensive assessment of the seismic safety of critical facilities statewide. Some but not all state and local agencies have identified facilities potentially at risk for their hazard mitigation plans or capital improvement plans. An effort also is ongoing to identify potential facilities at risk to potential terrorist attack by local and state homeland security initiatives. These efforts have not been coordinated, and assessments completed to date have not used a consistent methodology to determine seismic risk. Without such assessments, it will be difficult to develop strategies to reduce earthquake loss, and those that are will be inadequate. Implementing loss-reduction strategies requires funding and possibly legislation.

An example of such legislation documenting and improving the seismic safety of critical facilities is California's Alquist Act. Enacted following the 1971 Sylmar earthquake, which resulted in the destruction of two major hospitals and the loss of 65 lives, the act established a statewide seismic safety building standards program. Amendments to the Alquist Act made after the 1994 Northridge earthquake requires all acute-care hospitals to remain operational following a design earthquake, and to make seismic upgrades meeting certain performance criteria. Hospitals that do not meet performance criteria by specific deadlines outlined in the law must be removed from service. Implementation of this program has resulted in acute-care hospitals in California being operational immediately after recent earthquakes.

Priority Recommendation No. 3

Retrofit of High Risk Buildings

Develop local and state funding and legislation requiring mandatory seismic retrofits of high-risk buildings, such as unreinforced masonry and tilt-up structures.

Rationale:

During the 1949 and 1965 earthquakes in Puget Sound, buildings with unreinforced brick walls and sand-lime mortar experienced more damage than any other type of construction. For example, two schools closed and a church condemned in Centralia, bricks and masonry from a gable over the main entrance of the Castle Rock high school collapsed and killed one student, and 1,900 brick walls in Seattle that collapsed, fractured or bulged were condemned and removed. Schools experienced a disproportionate level of damage in these earthquakes because of their brick construction. Extensive damage to unreinforced masonry buildings also occurred in the 2001 Nisqually earthquake, with 20 of the 31 buildings in Seattle red tagged due to extensive damage being URM buildings; another 50 of this building type were yellow-tagged for moderate damage. Luckily, because of time of day or school being out of session, casualties from URM building collapse in these earthquakes were limited.

Unreinforced masonry building damage and collapse can be deadly. URM buildings that collapsed killed people in the 1989 Loma Prieta earthquake. For example, two people died in Santa Cruz when the façade of an adjacent URM building collapsed onto the coffee shop they were in. In the South of Market District in San Francisco, a man waiting in his car died when part of the URM building in which his wife worked collapsed on top of him. More recently, collapse of an unreinforced masonry clock tower caused the only two deaths in the December 2003 Paso Robles earthquakes in California.

In 1986, California enacted a law requiring local governments in high seismic zones to inventory unreinforced masonry buildings, establish a URM loss reduction program, and report progress to the state by 1990. Local governments tailored their programs to meet their individual needs. The level of compliance with this law is quite high, with about 98 percent of the 25,500 URM buildings in California now in some sort of loss-reduction program; only about two thirds of the owners have reduced losses by voluntary retrofitting their buildings. Further work by the California Seismic Safety Commission suggests that mandatory strengthening by local governments is the most effective URM loss reduction program; it also found that voluntary strengthening has not been as effective because current economic incentives typically are insufficient to create a market-driven willingness to retrofit.

After the 2001 Nisqually earthquake, the City of Seattle and other communities investigated similar programs, but the effort died for lack of funding. The State of Washington must provide guidance and leadership for cities and counties to take action to improve the life-safety in high-risk buildings with known seismic hazards.

Many of the 2,200 URM buildings in the three-county study area of this project are located in poor soils and in the zone of strongest shaking expected from the Seattle Fault. The same is true of older buildings of tilt-up construction, which are similarly vulnerable to strong ground shaking because of inadequate connections between the walls and roof. Many of these structures have little or no seismic improvements. Not requiring full retrofit of these high-risk structures may result in unnecessary casualties and injuries of hundreds of people.

Priority Recommendation No. 4

Protect the Transportation Infrastructure

Establish and implement a strategy to quicken the pace of protecting seismically vulnerable critical transportation infrastructure.

Rationale:

Transportation infrastructure, particularly freeways, highways and local bridges, is essential to the health of Washington's economy. Trucks move about a quarter-billion dollars worth of goods through the three-county study area of this report every day; final distribution of most goods such as groceries, pharmaceuticals and other medical supplies, fuel, office supplies, and more is by truck. Millions of tons of food products from Eastern Washington and beyond move through the region via rail and seaports. Three-quarters of domestic waterborne cargo tonnage entering Alaska originates from Washington. More than a quarter-million commuters cross county lines to go to work in the region.

A transportation system – particularly the road network and bridges – badly damaged by an earthquake will delay emergency response in the hours after the event, restrict the movement of people and goods for months, and hamper the recovery of the Puget Sound region and Washington for months or years.

The lessons of past disasters are instructive for the Puget Sound region. Damage to transportation systems from the 1995 Kobe, Japan earthquake slowed the recovery of the region's economy. The extended period needed to restore transportation systems cut cargo traffic in half at the Port of Kobe, the sixth largest container port in the world before the earthquake. During reconstruction, some shippers moved permanently to other undamaged ports. The same thing happened to the Port of Seward following the 1964 Great Alaska earthquake; much of Seward's business went to the Port of Anchorage. More than one-quarter of the business interruption loss in the 1994 Northridge earthquake was from highway damage and longer commutes; losses would have been far greater were it not for the substantial redundancy in the Los Angeles highway network. During the 1993 Great Midwest Flood, business interruption losses in Des Moines, IA, caused by transportation disruptions were greater than damage caused by the flooding itself. City, county and state agencies have been proactive in retrofitting their transportation assets, particularly bridges. However, financial resources limit their activities. For example, with current levels of funding it will take the Washington State Department of Transportation until 2070 to retrofit all state bridges in the current retrofit program above the ground (with the exception of the Alaskan Way Viaduct and those bridges with hollow core piles). This is a very long time. Furthermore, many bridges are located on steep hills or beside water where soil movements due to slides or liquefaction may cause severe structural distress. Unfortunately, foundation and soil remediation work is not part of the current retrofit plan, so failure of even the retrofitted structures during strong ground motions is possible.

Since the road-based transportation system is vital to both the immediate and long-term economic health of the state – regardless of whether there is a disaster – not increasing the pace of retrofitting soon will contribute to increased costs later, as well as large additional losses in terms of deaths, dollars and downtime from an earthquake disaster.

Other Recommendations of the Seattle Fault Earthquake Scenario Project Team

Recommendation No. 1

Accelerate Earthquake Hazard Assessments, Geological Mapping and the Use of these Studies

Continue to expand and improve information and maps on earthquakes and related geologic hazards, and require their use as best available science for state building codes, local land-use planning and development decisions, and local and state emergency response, recovery and continuity plans. Such work includes completing LIDAR mapping of all lowland fault systems in Western Washington and selected fault systems in Eastern Washington, and accelerating geologic mapping in urban areas and along critical transportation corridors.

Rationale:

In the 12 years since the U.S. Geologic Survey and others discovered that the Seattle Fault is active, there has been much progress understanding earthquake hazards and incorporating new scientific knowledge into products that help reduce the region's earthquake risk. In the past year, the Washington State Department of Natural Resources updated state soil and liquefaction zone maps, the University of Washington published new geologic maps of Seattle and the Tacoma area, and the U.S. Geologic Survey documented active faulting in Snohomish County along the Southern Whidbey Island Fault. Despite this progress, there is continuing uncertainty about the hazards posed by crustal faults and the strength of expected ground shaking.

Completing LIDAR mapping in Western Washington and in selected areas of Eastern Washington is the single most important step in reducing uncertainty surrounding earthquake hazard assessments of crustal faults. LIDAR is a high-resolution laser-based technology that allows geologists to document active crustal faults. Some LIDAR mapping has been completed in Puget Sound, but not yet over some of the main faults including the Doty Fault in Lewis County, the western portion of the Devils Mountain-Darrington Fault in Skagit and San Juan Counties, and an area in Spokane hit in recent years by a swarm of very shallow earthquakes. LIDAR also allows development of detailed landslide inventory maps, the first step in making landslide hazard maps; outside of Seattle, landslide hazard maps are generally poor or non-existent

It is necessary to accelerate the pace of producing digital geological maps complete with online, digital geotechnical databases of the state's urban areas. Digital maps form the starting point of virtually all major capital construction projects in Washington; while some areas such as Seattle have both modern geologic maps and digital databases, most areas do not. The databases are important not only for improved seismic engineering and estimates of strong ground shaking, but they also contribute to better design for other hazard reduction initiatives, such as anti-terrorism measures.

Better information about geological features will improve implementation of the 2003 International Building Code and enable better informed emergency response and recovery planning, critical areas designations, land-use planning decisions, and engineering solutions for new construction and building retrofits. Mandating use of this best available science will reduce the number of poor decisions for land-use planning and building design and construction.

Recommendation No. 2

Develop Incentives for Increased Seismic Safety

Develop financial and other incentives to increase the level of seismic safety in public and private buildings through structural and non-structural mitigation measures.

Rationale:

Incentives are designed to stimulate action while providing some reward or benefit to the individual or entity taking the action. It must be clear that the benefit will exceed the cost of the action taken. Incentives generally are required for owners of private and public buildings as they typically do not perform structural and or non-structural retrofits on their own initiative. Incentives can include tax reductions and credits, special purpose loan programs, and waiving of building permit and development fees, for example.

Development and implementation of appropriate incentives for various types of buildings and building owners is a complex undertaking, and will require much work by the various stakeholders involved – building owners and managers, earthquake professionals, taxing agencies, mortgage lenders, and insurance companies, among others. Encouraging owners through incentives to protect their own buildings will reduce deaths, dollars and downtime associated with a major earthquake and other disasters.

Recommendation No. 3

Expand Public Education Programs with Emphasis on Self-Sufficiency

Develop innovative programs to educate the public, public agencies, and the business community that both appropriately communicates the risk posed by earthquakes and generates action by individuals and organizations so they are self-sufficient for at least 72 hours following an earthquake.

Rationale:

A variety of public, private and non-profit organizations have spent hundreds of thousands of dollars in recent years to educate the public about Washington's earthquake hazard, actions to take in advance to prepare for earthquake as well as actions to take after the event has occurred. Public educators had not followed up to determine the effectiveness of their message nor whether individuals, families, or public and private organizations were any better prepared. The 2001 Nisqually earthquake provided researchers an opportunity to find out more about the level of knowledge of the earthquake threat and the level of preparedness.

Two studies of the impact of the Nisqually earthquake found the 2001 event did not stimulate the majority of households and small businesses to change their level of earthquake preparedness. One study showed that before the Nisqually event, less than half of the Puget Sound region's households had taken steps to prepare for an earthquake, and that afterward, four of five households did not increase their level of preparedness. The second study showed that 60 percent of small businesses lost productivity because of the Nisqually event, but only one third of small businesses increased their level of preparedness afterward. The firms increasing their preparedness were not the ones that necessarily experienced the most damage, but the ones that had taken precautions before. In other words, the careful grew more careful.

It is clear that many people, organizations, and businesses do not fully understand the region's earthquake threat nor have they fully considered what could happen when a major earthquake strikes. They believe that having survived the Nisqually event they are well prepared for the next earthquake. As a result, preparations to deal with a major earthquake such as an event on the Seattle Fault are inadequate. The public education status quo is not working effectively.

Improving the level of awareness and of preparedness in our communities must be a goal of both potentially impacted communities and the state. Public education programs must be revised and retooled to better address the Puget Sound region's and the state's earthquake threat and so people and organizations are compelled to take action to prepare for the next major earthquake.

Without strong public education programs that spur action, too many individuals, households, and businesses will not be ready for the next major earthquake. This will lead to more deaths, injuries, damage, lost productivity, a reduced level of response, and a reduced capability to recover.

Recommendation No.4

Enhance the Pacific Northwest Seismographic Network

Provide adequate funding to upgrade the region's seismograph network to make it more robust and to enhance its capabilities. This includes support from the State of Washington for federal funding initiatives such as the U.S. Geological Survey's Advanced National Seismic System, the National Earthquake Hazard Reduction Program and an enhanced National Tsunami Hazard Mitigation Program.

Rationale:

The Pacific Northwest Seismograph Network is one of the country's premier regional seismic networks, monitoring earthquake and volcanic activity across Washington and providing earthquake location and magnitude estimates in real time to emergency response organizations and the public. Data collected by the network, including that from 80 new urban strong motion stations, is key to understanding the effects of shaking on buildings and structures. The PNSN website (www.pnsn.org) has millions of visitors each year, and public agencies and the media depend on its staff to interpret seismic activity and current hazards research.

Despite its capabilities and reputation, the network's current finances do not allow for replacement of old equipment or installation of additional, modern instruments that will allow state and local communities to take full advantage of the network's existing products and real-time products under development. (Currently, the U.S. Geological Survey largely funds the network through both the National Earthquake Hazard Reduction Program and the Advanced National Seismic System Program; the U.S. Department of Energy in recent years, however, reduced funding for monitoring in the Hanford area.)

Ensuring rapid dissemination of earthquake-related information from locations anywhere in the state requires modernizing and expanding the seismic network, particularly in Eastern Washington. One area needing additional monitoring stations runs from Spokane south through Pullman and Clarkston. In addition, much of the network's existing equipment is old, installed in the 1960s and 1970s. This equipment lacks the capability of recording information needed for a rapid assessment of an earthquake. The ANSS management plan calls for federal funds to replace old seismic instruments and to improve monitoring statewide by adding 600 more strong motion stations, key for addressing engineering design issues.

The state and local communities should encourage Congress to fully fund the Advanced National Seismic System and ensure that newly installed seismic stations along the coast deployed specifically to monitor the Cascadia subduction zone include strong ground motion recording. Also, the state should develop a plan to bring real-time earthquake information to all county and city emergency managers using multiple communication channels. The ANSS has new real-time display systems, but currently there is no national strategy to ensure deployment of these systems.

Recommendation No. 5

Establish an Earthquake Information Clearinghouse

Establish an earthquake information clearinghouse to improve access to best available science and best practices for earthquakes and related geologic hazards in Washington for the public, government agencies, businesses and other organizations.

Rationale:

An earthquake information clearinghouse would provide the public, local planners, emergency managers, business contingency planners, engineers, researchers and others with information relevant to the state's earthquake threat and related to increasing earthquake safety. Providing a portal for this information would make it easier for homeowners, organization managers, and building owners to develop forward looking response and recovery plans as well as mitigation initiatives to reduce earthquake loss.